USING INTERRUPTIONS TO STUDY ASSOCIATIONS IN PROSPECTIVE MEMORY

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USING INTERRUPTIONS TO STUDY ASSOCIATIONS IN PROSPECTIVE MEMORY IN AN AIR TRAFFIC CONTROL SIMULATION

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For Neha and Sudeep

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SUMMARY

Background: Prospective memory (ProM) consists of remembering that some action needs to be performed in the future and when (detecting the Intent Trigger), and what the action is (Recalling the Content of the trigger). The Intent Trigger is bound by a forward association to the Content Recall, and the Content Recall has a backward association to the intent Trigger. In situations which present multiple, interleaving ProM tasks to operators it is not known how subsequently-presented ProM tasks interfere with the associations between the Intent Trigger and Content Recall of the original ProM task. **Objective:** The current study investigated the effect of presenting multiple, interleaved ProM tasks on timely detection of the Intent Trigger and accurate Recall of the Content of the original ProM task. **Method:** Participants encoded a ProM task (AB) in an air traffic control simulation. They then were interrupted with a second ProM task. The ProM interruption task was different from the original ProM task in either the Intent Trigger (AB, CB), Content Recall (AB, AD), or both Intent Trigger and Content Recall (i.e., a new ProM task, AB, CD). A control condition involved interrupting the participant with a weather report. **Results**: Detection of the Intent Trigger was significantly worse after a ProM interruption as compared to a weather interruption; a similar pattern of results, but with marginal significance, was also found for Content Recall. Additionally, a ProM task that interfered with backward association (AB, CB) was no better or worse than doing two unrelated ProM tasks (AB, CD) on the detection of the Intent Trigger. However, a task that presented a new forward association (AB, AD) was worse than performing two unrelated ProM tasks (AB, CD) on Recall of the Content. The results are

discussed in the context of designing memory aids to support interleaved ProM tasks in dynamic environments.

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CHAPTER 1

INTRODUCTION

Operators in dynamic environments, such as air traffic control, may often postpone the implementation of certain intentions because of being engaged in other tasks in the current moment (Loft, Smith, & Bhaskara, 2011; Vortac, Edwards, & Manning, 1995). For example, an air traffic controller (ATCo) may be unable to immediately grant a pilot's request of flying a direct route if engaged in tasks such as ensuring minimum separation distance between aircraft or accepting and handing off aircraft to or from other sectors. Intentions or actions that are deferred to be performed at a specific future point in time or in response to an appropriate retrieval cue are called prospective memory (ProM) tasks.

Even though research interest in ProM has been fairly recent as compared to retrospective memory (Meacham & Leiman, 1982), there is a rapidly developing body of knowledge on various facets of ProM. Researchers now distinguish between event-based tasks which are to be executed after encountering a specific cue, and time-based tasks which are to be executed at a specific time of the clock (Einstein & McDaniel, 1990). Performance on time and event-based ProM tasks has been measured in various populations such as younger and older adults (Einstein & McDaniel, 1990) and in various settings including the laboratory and the real world (Uttl, 2008). Although lab-based tasks measuring both event- and time-based ProM have found age decrements, improvements with age were found on both tasks in the natural settings, presumably because ongoing tasks in the laboratory demand more resources than those in naturalistic settings (Bailey, Henry, Rendell, Phillips, & Kliegel, 2010; Uttl, 2008).

The growth of research on ProM in the last two decades was made possible by the development of the delayed-execute paradigm (Einstein & McDaniel, 1990). This paradigm to study ProM in the laboratory involves embedding the ProM task within another "primary" ongoing task. An experiment using this paradigm may ask people to make judgments about whether strings are words or not; this lexical decision task is communicated as the primary task of the experiment. Participants then memorize a list of words and are told to remember to press the spacebar key if they see those words on the lexical decision task. However, the key press is to be delayed until the completion of the primary task. In this instance, successful performance of the ProM task entails recognizing the target word as a ProM cue while performing the lexical decision task and also remembering the action associated with the target word – pressing the spacebar key. In this way, successful performance of a ProM task using the Einstein-McDaniel paradigm depends on multiple factors - recognizing the ProM cue, identifying it as distinctive from the surrounding stimuli, associating it with the ProM content, and initiating retrieval of the associated content.

Components of Prospective Memory

Einstein, Holland, McDaniel and Guynn (1992) differentiated between two components of a ProM task: remembering that some action needs to be performed and when, and remembering the specific details of the action. The former is called the prospective component, or detection of the intent trigger and the latter is referred to as the retrospective component, or the recalling the content (Vortac et al., 1995).

The intent trigger and content recall can be considered distinct from one another because they draw from separable cognitive resources (Cohen, West, & Craik, 2001; Smith & Bayen, 2004). Whereas there is a general consensus that retrospective memory resources are involved in recalling the content (e.g., Cohen, Dixon, Lindsay, & Masson, 2003; Smith & Bayen, 2004), there is a debate about the resources required to successfully detect the intent trigger. The preparatory attentional and memory (PAM; Smith & Bayen, 2004) theory argues that detection of the intent trigger will always recruit preparatory attentional processes to monitor the environment for the occurrence of the retrieval cue. In contrast, the multiprocess theory (McDaniel & Einstein, 2000) argues that detecting the intent trigger will be automatic when the retrieval cue is salient or familiar. Strategic attentional resources will be required only when the retrieval cue is not salient.

Knowledge about the resources consumed by the intent trigger and content recall is useful in designing aids to perform ProM tasks (Loft, Smith, & Bhaskara, 2011). ProM aids are important, especially in dynamic environments where ProM failures could result in substantial losses. For example, forgetting to perform a ProM task in air traffic control, such as forgetting to reinstate a pilot's request for landing after a period of high air traffic may results in financial losses. If recalling the content is automatically triggered by salient environmental cues then dynamic environments should provide operators with memory aids that capture attention and facilitate in triggering the content of a ProM task. However, if the recognition of a cue always requires preparatory attentional processes, then dynamic environments should be designed in a manner that encourages operators to engage in preparatory attentional processes at the appropriate moment. In addition to making use of knowledge about resources required to perform ProM tasks, ProM aids can also benefit recall by leveraging associations inherent in ProM tasks.

Associations in Prospective Memory

There are numerous associations underlying the various parts of ProM tasks. Associations exist between the ongoing task and the ProM task, and also between the intent trigger and content recall of the ProM task. Inherent associations between the parts of a ProM can be leverages to design ProM aids. One such association is that between the ongoing task and the ProM task.

Nowinski and Dismukes (2005) applied the principle of encoding specificity (Tulving & Thomson, 1973) to manipulate the association between the ongoing task and the ProM task. The encoding specificity principle states that encountering the same context at encoding and retrieval facilitates memory retrieval. To test the applicability of this principle, participants were presented with two ongoing tasks, one of which was explicitly associated with instruction for the ProM task. Results showed that execution of the ProM task was significantly better in the associated ongoing task condition as compared to the non-associated ongoing task condition. Associating both ongoing tasks with instructions to perform the ProM task eliminated differences in the execution of the ProM task. Thus, reinstating the encoding context at the time of retrieval benefits ProM performance.

Implementation intentions have also been used to strengthen the association between the or ongoing task and the cue signaling the intent trigger of the ProM task (Gollwitzer, 1999). In forming an implementation intention, a person verbally states that upon encountering the ProM cue within a particular situation, he or she will engage in a particular behavior - the execution of the ProM task (Gollwitzer, 1999). By making explicit the association between the anticipated characteristics of the ongoing task when encountering the ProM cue, implementation intentions presumably automatize cue detection, and consequently, the execution of the ProM task.

However, implementation intentions are not always effective. McDaniel and Scullin (2010) found that using implementation intentions did not facilitate ProM when the ongoing task required substantial resources. Engaging in resource demanding ongoing tasks would not leave available sufficient resources to engage the preparatory attentional processes required to detect the ProM cue (Smith, 2003; Smith & Bayen, 2004). Thus, it is likely that implementation intentions would be ineffective ProM aids in safety-critical dynamic environments such as air traffic control. In air traffic control performing the continuous ongoing task of ensuring that aircraft are at safe distances from one another may consume substantial cognitive resources, thus leaving little attentional resources to effectively make use of implementation intentions - monitoring for the occurrence of the

ProM cue. In such situations, it may be more useful to leverage other associations, such as that between the intent trigger and content recall, to improve ProM.

Despite the differences in the cognitive resources consumed by the intent trigger and content recall, the two components are intrinsically associated with one another because the intent triggers the recall of the content. Once the intent trigger is active, the association between the trigger and the content may serve to cue the recall of the content. However, because preparatory attentional processes underlying the intent trigger are resource demanding, engaging in them continuously until the occurrence of the target event may be detrimental to efficient performance on the ongoing task.

Some research does in fact demonstrate improvement in ProM performance by using ProM aids that alert people just in time of execution of ProM tasks (Loft et al., 2011; Vortac et al.1995). Loft et al. (2011) found that within the context of air traffic control, a memory aid consisting of the content for a ProM task that flashed in coordination with the appearance of the target aircraft resulted in a lower rate of errors on the ProM task as compared to an aid which was present for the entire duration of the trial but did not alert participants at the appropriate moment. The memory aid worked by signaling to participants the appropriate moment to begin engaging in preparatory attention to recognize the correct aircraft and execute the content. From Loft et al.'s (2011) research it appears that merely presenting the content without signaling the intent trigger may be ineffective in successfully realizing a ProM task.

Thus, the nature of associations between the intent trigger and content recall are important in determining successful performance of a ProM task. However, little is understood about the involved associative processes. It may be useful, for example, to investigate not only how forward associations from the intent trigger to content recall influence ProM, but also the role of backward association from content recall to the intent trigger on ProM execution (Underwood & Schulz, 1960). Research on paired associate learning can be used to inform the study of associations in ProM. Specifically, once a person has encoded a ProM task, an interruption can be used to insert a second ProM task which is similar with the original ProM task on either the intent trigger or the content recall, or neither intent trigger nor content recall. The various paradigms of PAL can then be used to test specific predictions about the associations between the intent trigger and content recall of ProM tasks.

Using Paired Associate Learning to Study Prospective Memory

Paired associate learning (PAL) has been used to investigate the effect of manipulating associations between word pairs on subsequent memory for the latter word in the pair. Learning paired associates entails encoding a stimulus (e.g., A), a response (e.g., B), and the association between the stimulus and the response (e.g., A-B, Underwood & Schulz, 1960).

The relationship between the stimulus and the response is varied and tested through three phases: original learning (OL), interpolated learning (IL), and transfer. In the OL phase participants learn the initial association between the stimulus and the response, for example, A-B. In this phase subjects form a forward association from the stimulus to the response (A-B), and a weaker backward association from the response to the stimulus (B-A, Underwood & Schulz, 1960).

After learning the initial association between the stimulus and the response in the OL phase, participants go through the IL phase in which the associations between the two are manipulated. Participants may learn, for example, a new stimulus (e.g., C) and associate that with the old response (i.e., B), thus forming a new backward association from B to C. Alternately, participants may learn a new response (e.g., D) to the old stimulus (i.e., A), thus forming a new forward association from A to D. Or, participants may learn an entirely new stimulus-response pairing, for example, associating stimulus C with response D, and thus learn a new forward and backward association, neither related to the original A-B pair.

In the last phase of PAL, the transfer phase, participants are tested on their memory for the original word pairs (A-B). Participants are presented with the original stimulus (i.e., A) and are expected to respond with the word that it was paired with in the OL phase (i.e., B). Accurate performance on this phase thus requires remembering the response in OL along with recreating the initial forward and backward associations.

It is possible to think about learning in prospective memory as analogous to that in paired associates. Learning a ProM task entails remembering that something needs to be done and when (the intent trigger), remembering what has to be done (recalling the content), and establishing an association between these two pieces of information. If the intent trigger in ProM is considered to be the stimulus and content recall as the response, then ProM may essentially be reconceptualized as an intent trigger-content recall paired associates learning task. Once a ProM task has been encoded, interruptions can be used to introduce a second ProM task that varies in its relationship to the stimulus or response of the original ProM, thus recreating the IL phase in PAL.

<u>Pairing a new intent trigger to the same content recall</u>

The effect of varying the relationship between the intent trigger and content recall in ProM may be tested by using the various paradigms of PAL. Pairing a new intent to the same content in the IL phase is analogous to the AB, CB paradigm in PAL (Underwood & Schulz, 1960). After learning the association between stimulus A and response B in the OL phase, participants then learn a new stimulus, C, and associate C with the old response B (see Figure 1, Condition A). Thus, participants have to replace the backward association of B to A with a new backward association of B to C. Impaired learning of the C-B pair in the IL may result from proactive interference from the initial association between A and B (Crouse, 1968).

In the transfer phase participants are presented with the original stimulus, A, and are expected to respond with the original response of B. Impaired performance on the transfer phase may be attributed to retroactive interference on the backward association of B-A from the newly acquired backward association of B-C.

The research from ProM can be used to reach a similar prediction (Einstein, Smith, McDaniel, & Shaw, 1997; Kidder et al., 1997). Addition of a new ProM task should result in an increase in the amount of preparatory attention needed to monitor for the occurrence of the retrieval cue, resulting in impaired recall of the OL pair (Smith, 2003).

Pairing a new content recall to the same intent trigger

Pairing a new content recall to the same intent trigger in the IL phase is analogous to the AB, AD paradigm in PAL (Underwood & Schulz, 1960). After learning the association between stimulus A and response B in the OL phase, participants learn a new response, D, in association to the old stimulus A (see Figure 1, Condition B). Thus, participants have to replace the forward association of A to B with a new forward association of A to D. Impaired learning of the A-D pair may result from proactive interference from the initial association between A and B (Crouse, 1968).

In the transfer phase participants are presented with the original stimulus, A, and are expected to respond with the original response of B. Impaired performance on the transfer phase may be attributed to interference from associating a different and unrelated response to the same stimulus. (Martin, 1965; Postman & Keppel, 1969).

The ProM literature predicts worse ProM performance when multiple contents are associated with the same intent in both the original ProM task and interrupting ProM task (Cook, Marsh, Hicks, & Martin, 2006). Cook et al. (2006) used the fan effect to investigate the effect of manipulating content recall on ProM performance. A single intent trigger had either a small associative fan (i.e., it was associated with only one content recall), or a large associative fan (i.e., it was associated with four content recalls). Prospective memory performance was measured in terms of triggers that were detected and responded to with the correct content recall. Results showed that participants were worse in detecting the trigger in the large fan condition, i.e., when it was associated with multiple contents. Impaired cue detection in the multiple cue condition can be attributed to the increase in the retrospective memory resources required to hold multiple responses in memory while also associating all content recalls with the same intent trigger.

Pairing a new intent trigger to a new content recall

Learning a new pair of intent trigger - content recall pair in the IL phase is analogous to the AB, CD paradigm in paired associates learning (Underwood & Schulz, 1960). After learning the association between stimulus A and response B in the OL phase, participants learn a new stimulus, C, and associate it with a new response, D (see Figure 1, Condition C). In the transfer phase participants are presented with the original stimulus, A, and are expected to respond with the original response of B.

Past research indicates no impairment in the transfer phase in the AB, CD paradigm as compared to the AB, AD or the AB, CB paradigm (e.g., Crouse, 1968). This is because learning the association between C and D should not be subject to interference from forward associations or backward associations acquired with learning of the associations between A and B. Thus, the literature from paired associate learning would predict intact performance on the transfer phase.

The literature from ProM makes a different prediction from the literature on paired associates learning regarding performance on the AB, CD condition. Presenting a new ProM task should increase the amount of preparatory attention required to monitor for the occurrence of the retrieval cue for the new task (Smith & Bayen, 2004). There should also be an increase in the memory processes required to distinguish the two retrieval cues from each other and from other events. Therefore, the PAM theory would predict worse performance in the transfer phase when two ProM tasks have to be executed (Smith & Bayen, 2004).

In this way, past research on PAL and ProM can be used to test specific predictions about the varying the association between the intent and content in ProM. The relationship between the intent trigger and content recall can be varied by presenting a new ProM task. Interruptions can be used to insert new ProM tasks that vary in similarity from the originally presented ProM task.

Interruptions and Prospective Memory

It is important to study the effect of interruptions on ProM because interruptions to ProM tasks may frequently present a second ProM task. A failure to correctly execute the original ProM task or the interrupting ProM task may have especially troublesome consequences in safety-critical environments such as healthcare or air traffic control. For example, an ATCo who is holding a ProM task of issuing a lower altitude to aircraft X in 15 minutes may be interrupted by a request to issue a different altitude change to aircraft Y after the next 20 minutes. The two ProM tasks have to be remembered and correctly executed in addition to performing other tasks such as communicating with other ATCos and pilots and ensuring safe separation distances between aircraft. In this situation, the ATCo has to not only devote resources to keep performance high on the ongoing tasks, but also monitor for the occurrence of the retrieval cues associated with performing correctly the two ProM tasks. Interruptions can be used to understand how similarity between two ProM tasks influence not only remembering to execute the distinct ProM tasks but also what has to be done to successfully complete each task.

Interruptions are detrimental to the completion of ProM tasks (Dodhia & Dismukes, 2009; McDaniel, Einstein, Graham, & Rall, 2004). Embedding an interruption in the interval between encoding a ProM task and its execution (the retrieval phase) results in lower accuracy in performance of a ProM task as compared to no interruption in the retrieval phase (McDaniel et al. 2004). This effect persists regardless of the length of the interruption. One reason for reduced ProM performance following an interruption is because interruptions occur suddenly, force the suspension of current task goals while dealing with the interruption, and create task-switching costs (Dodhia & Dismukes, 2009). Further, an inability to recognize or predict the conclusion of the interruption may result in a reduced opportunity to interpret cues to resume the ongoing task (Dodhia & Dismukes, 2009).

In addition to helping study the effect of sequentially encoded similar ProM tasks, using the interruption methodology to study ProM offers other benefits. First, the presentation of an additional ProM task through an interruption allows for selective and relatively independent interference with the intent trigger and content recall of a previously-encoded ProM task. Second, the interruption methodology contributes to the literature on the influence of interruptions on ProM. In the literature so far, researchers have not investigated the effect of instructing participants to perform a second ProM task while they are in the midst of monitoring for the intent trigger cue of a previously-encoded ProM task. It may be possible that some of the difficulty of investigating this phenomenon is due to the lack of an appropriate methodology. The current study proposes a way to combine two previous bodies of literature (interruptions and paired associate learning) to investigate this phenomenon. Third, the proposed method allows for the examination of the effect of similarity of components between successively presented ProM tasks on the successful performance of such tasks. This characteristic of similarity between ProM tasks may be especially pertinent to the study of real-life ProM demands in air traffic control. Air traffic controllers may often encode new ProM tasks while they are at various stages of completion of previously-encoded ProM tasks. Examples of ProM tasks in air traffic control include remembering to change altitude, speed, or routes of certain aircraft. It is possible that ProM tasks which are successively presented, and which are similar in individual components with previously-presented

ProM tasks present controllers with special memory challenges. The current study draws from predictions in paired associates learning to address problems associated with successively encoding ProM tasks that share similarities in individual components with previously encoded ProM tasks.

However, there may be some limitations to the analogy of paired associate paradigms when predicting the effect of interrupting a ProM task with a second ProM task. The effects of paired associate are obtained from list-learning and not from learning associations between single items. The intent trigger-content recall pairings proposed in the current experiment involve associations between single items. Therefore, it may be possible that the associative strength between intent trigger-content recall pairings on the initial ProM task may not be sufficient to cause an interference with learning a new association between the intent trigger and content recall in the interrupting ProM task. Nevertheless, the paired associate analogy serves as a useful heuristic to guide the investigation of the components of ProM.

Current study

The current study investigated associations between the intent trigger and content recall in ProM in air traffic control by leveraging two areas of research - paired associate learning and interruptions. Participants were instructed that their main task was monitoring the airspace for aircraft conflicts. Once a participant encoded a ProM task, they experienced interruptions. The interruption either presented a second ProM task to them or simply gave information about the weather in a specific part of the airspace. Thus, the weather interruption did not present a ProM task to the participant.

Participants were expected to remember to perform the ProM tasks in addition to the ongoing task of monitoring for aircraft conflicts. There were two dependent measures 1) detection of the ProM trigger within 60 seconds of its appearance 2) accurate recall of the content-the correct route to which the ProM aircraft had to be rerouted to. The dependent measures were taken only for the interrupted ProM aircraft. Thus, the current study measured performance on the transfer phase of PAL.

The ProM interruption (henceforth referred to as interrupting ProM task), presented a second ProM task to participants. The interrupting ProM task interfered with the preparatory attentional processes required to notice the intent trigger of the original ProM task (henceforth referred to as the interrupted ProM task) and the retrospective memory processes required in recalling the content of the interrupted ProM task, or only preparatory attention or only retrospective memory. The interrupting ProM task selectively changed the relationship between the intent trigger and content recall of the interrupted ProM task in one of three ways – 1) by presenting a new intent trigger and content recall 2) a new intent trigger, or 3) a new content recall. Figure 2 illustrates the sequence of the interrupted ProM task and the interrupting ProM tasks.

<u>Comparing non-ProM interruption (weather) to control ProM interruption (AB, CD)</u>

There were three types of interrupting ProM tasks. One type of interrupting ProM task presented participants with both an intent trigger and content recall that were different from those of the interrupted ProM task (AB, CD). The condition named "intent trigger + content recall change" in Table 1 provides an illustration of the AB, CD condition. For example, if the interrupted ProM task instructed participants to remember to reroute any U5 type of aircraft to route f-d-s from waypoint f, then the interrupting ProM task instructed participants to reroute a different type of aircraft, e.g., E9, to a different route of j-d-p.

The paired associate learning literature would predict that performance on the transfer phase (detecting U5 and rerouting it to f-d-s) will not be influenced by forward or backward associations from the interrupting ProM task. This is because the intent trigger and content recall of the two ProM tasks are different. From the perspective of PAL, the AB, CD manipulation will help in understanding the effect of presenting a cognitive load that is entirely different from that of the interrupted ProM task; it may thus be considered as the control condition for having to complete two ProM tasks.

The ProM literature would predict that as compared to remembering to perform a single ProM task, presentation of a second, unrelated ProM task would recruit additional preparatory attentional and retrospective memory processes (Cook et al., 2006; Smith & Bayen, 2004). Therefore, performance on the AB, CD task would be worse as compared to the weather interruption. Based on this prediction, the following hypotheses were examined (Hypothesis 1 measured the DV of intent trigger and Hypothesis 2 measured content recall):

Hypothesis 1

Participants will detect fewer interrupted aircraft in a timely manner in the AB, CD ProM interruption condition as compared to the AB, CD weather interruption condition.

Hypothesis 2

Participants will recall routes of fewer interrupted aircraft in the AB, CD ProM interruption condition as compared to the AB, CD weather interruption condition.

Comparing control ProM interruption (AB, CD) to intent trigger change ProM (AB, CB)

A second type of interrupting ProM task presented participants with the same content recall, but a different intent trigger from that of the interrupted ProM task (AB, CB). For example, if the interrupted ProM task instructed participants to remember to reroute any U5 type of aircraft to route f-d-s from waypoint f, then the interrupting ProM task instructed them to reroute a different type of aircraft, e.g., E9, to the same route of f-d-s. This condition will be referred to as an "intent trigger change". Table 1 provides an illustration of the intent trigger change condition. As the table illustrates, the intent changes from “A” in the interrupted ProM task to “C” in the interrupting ProM task, whereas the content (B) remains the same.

The AB, CB manipulation will help in understanding the effect of changing backward associations from content recall to the intent trigger. Backward association from the interrupting ProM condition (B-C) may interfere with detection of the interrupted ProM aircraft (A) in the transfer phase. In comparison, detection of the interrupted ProM aircraft in the AB, CD condition will not be hindered by any forward or backward association. Based on these predictions, the following hypothesis was examined:

Hypothesis 3

Having the same content associated with two different intents (AB, CB) will be worse than two unrelated prospective memory tasks (AB, CD) on timely detection of the intent trigger.

Comparing control ProM (AB, CD) to content recall change ProM (AB, AD)

A third type of interrupting ProM task presented participants with the same intent trigger as that of the interrupted ProM task, however, with a different content recall (i.e., AB, AD). For example, if the interrupted ProM task instructed participants to remember to reroute any U5 type of plane to f-d-s from waypoint f, then the interrupting ProM task instructed them to enter a different route on the same type of aircraft, e.g., reroute only the next U5 aircraft to j-d-p. The condition named “content recall change” in Table 1 provides an illustration of this condition. As the table illustrates, the content recall changes from “B” in the interrupted ProM task to “D” in the interrupting ProM task, whereas the intent trigger (A) remains the same.

The AB, AD manipulation will help in understanding the effect of changing forward associations from the intent trigger to the content recall. The newly formed forward association from the intent trigger to content recall in the interrupting ProM condition (A-D) may interfere with recall of the correct content (B) of the interrupted ProM aircraft in the transfer phase. In comparison, content recall of the interrupted ProM aircraft in the AB, CD condition will not be hindered by any forward or backward association. Based on these predictions, the following hypothesis was examined:

Hypothesis 4

Having the same intent associated with two different contents (AB, AD) will be worse than two unrelated prospective memory tasks (AB, CD) on correct recall of the content.

CHAPTER 2

METHODOLOGY

Participants

One hundred and four participants were recruited from the online experimental sign-up system (Experimetrix) for undergraduate students at the Georgia Institute of Technology. Six participants did not correctly follow the instructions and were excluded from data analysis. Of the remaining 96 participants 59 were males and 37 were females. Participants' age ranged from 18 years to 24 years (M= 19.64 years, SD = 1.45). All participants were fluent English speakers, reported normal or corrected-to-normal vision and hearing, and received one Experimetrix credit for participation.

Apparatus

The experiment was individually administered to participants in an enclosed room on a computer with a high resolution color monitor and noise canceling headphones. Software included NextSim, a next generation (NextGen) air traffic control (ATC) simulator (NextSim, Durso, Robertson, & Stearman, 2010), and the Symmetry Span task (Kane et al., 2004). A post-task questionnaire querying participants about specific events during the experiment was administered at the conclusion of the study.

NextSim

NextSim simulates air traffic control airspace. Embedded within the airspace are aircraft, waypoints, and gates. Waypoints were used to create routes that aircraft followed until they reached their destination. All aircraft followed waypoints to traverse through the airspace until they reached sector gates from where they exited the airspace.

The features of the aircraft were contained in the data blocks, which were attacheded to aircraft. The data blocks contained the call sign, type of aircraft, current and assigned speed, current and assigned altitude, and route of the aircraft. Aircraft had different routes, maximum speed (300 - 900 nautical miles per hour), and altitude (10, 000 – 50, 000 feet). All aircraft were required to maintain a minimum radius of 2.5 miles lateral separation and 1,000 feet vertical from all other aircraft. Every time aircraft violated minimum separation, aircraft in conflict flashed red and emitted a warning tone. Participants resolved aircraft conflicts by right clicking on the data block of the aircraft and changing the altitude and speed.

Design

The ongoing task of the participants was monitoring aircraft for violations of minimum altitude separation standards. The ProM task was remembering to change the route of a specific type of aircraft once it reached a certain waypoint in the airspace (e.g., "reroute all U5 aircraft to f-d-s after the aircraft reached waypoint f"). This was the interrupted ProM task. It can be represented as A-B, where A is the intent trigger - detecting the U5 aircraft, and B is the content to be recalled - changing its route to f-d-s.

A 2 x 2 x 3 (Type of interruption x Order of presenting the interruptions x Memory load of the interrupting ProM task) factorial mixed design was used in the experiment. The type of interruption was a repeated measures factor and had two levels - a ProM interruption and a non-ProM interruption. A ProM interruption (i.e., the interrupting ProM task) presented participants with an interruption that assigned them a second ProM task. In contrast, the non-ProM interruption (weather interruption) did not require participants to remember a second ProM task but instead only presented them with information about adverse weather in a specific part of the airspace (e.g., thunderstorms near waypoint m).

The memory load of the interrupting ProM task was a between-subjects factor with three levels. Participants were presented with one of three interrupting ProM tasks. The interrupting ProM task was dissimilar from the interrupted ProM task in intent trigger (intent trigger change; C-B), content recall (content recall change; A-D), or both intent trigger and content recall (intent trigger + content recall change; C-D).

In the intent trigger change condition participants had to encode an interrupting ProM task with an intent trigger that was different from that of the interrupted ProM task. It may be compared to the AB, CB paradigm in paired associates learning (PAL). Specifically, if the interrupted ProM task was remembering to change the route of any U5 aircraft to f-d-s, then participants in the intent trigger change condition were instructed to enter the same route as the interrupted ProM aircraft on a different type of aircraft (i.e., reroute ONLY the next E9 aircraft to f-d-s). Thus, the interrupting ProM task in this condition selectively changed the memory load associated with the intent trigger of the interrupted ProM task.

In the content recall change condition participants had to remember an interrupting ProM task with a content recall that was different from that of the interrupted ProM task. It may be compared to the AB, AD paradigm in PAL. Specifically, if the initial ProM task was remembering to change the route of all U5 aircraft to f-d-s, then participants in the content recall change condition were instructed to enter a different route for ONLY the next U5 aircraft (reroute only the next U5 aircraft to j-d-p). Thus, the interrupting ProM task in this condition selectively changed the memory load associated with the content recall of the interrupted ProM task.

In the intent trigger + content recall change condition participants had to remember an interrupting ProM task with an intent trigger and content recall that were different from that of the interrupted ProM task. It may be compared to the AB, CD paradigm in PAL. Specifically, if the interrupted ProM task was remembering to reroute any U5 to f-d-s, then participants in the intent trigger + content recall change condition were instructed to enter a different route on a different type of plane (i.e., reroute ONLY the next E9 to j-d-p). Thus, the interrupting ProM task in this condition selectively changed the memory load associated with both the intent trigger and content recall of the interrupted ProM task.

Table 1 presents the three interrupting ProM conditions. A-B was the intent trigger-content recall pairing of the interrupted ProM task in all the three conditions. In the intent trigger change condition, AB, CB, the only difference between the interrupted ProM task and the interrupting ProM task was in the intent trigger, or the type of aircraft (U5 vs. E9). In the content recall change condition, AB, AD, the only difference between the interrupted ProM task and the interrupting ProM task is in the content recall, or the action to be performed on the aircraft (rerouting to f-d-s vs. rerouting to j-d-p). In the intent trigger + content recall change condition, AB, CD, the differences between the interrupted ProM task and the interrupting ProM task were in the intent trigger or the type of aircraft (U5 vs. E9), and the content recall, or the action to be performed on the aircraft (rerouting to f-d-s vs. j-d-p).

The manipulation of ProM change is meaningless when the interrupting event is weather. Thus, the variable was dummy coded for ProM load when weather was the interrupting event. Any differences across ProM load when weather was the interruption would be due to differences among participants in the condition and uncontrolled variance.

The second between-subjects factor was the order of presenting the interruptions. In the Weather 1st condition participants were first interrupted with the non-ProM interruption (weather report) and then the ProM interruption. In the Weather 2nd condition participants were first interrupted with the ProM interruption and then with the weather interruption.

There were two dependent measures of the ProM task – the intent trigger and the content recall. Both of these were measured in the transfer phase of the experiment in which participants were instructed to reroute all U5 types of aircraft to "f-d-s" from waypoint f. The intent trigger was measured by whether participants detected the correct ProM target aircraft within 60 seconds. In this instance, remembering that an action was to be performed on a U5 aircraft within 60 seconds, and when that action is to be performed (when U5 reaches waypoint f) was the intent trigger. The content recall was measured by whether participants entered the correct route on the appropriate ProM aircraft. With regards to the interrupted ProM task, for example, remembering the details of the specific action (reroute to f-d-s) was the content.

Procedure

Counterbalancing was used to create six orders of six combinations of the between-subjects factors. A random number generator was used to determine the sequence of presentation of the orders. After obtaining consent for participation, participants were randomly assigned to one of the six conditions.

Participants were trained on the features of the NextSim through instructional slides and practice scenarios. The slides provided information about the different features on the NextSim airspace and procedures on rerouting airplanes, avoiding conflicts, and managing interruptions; these were followed by short practice scenarios on NextSim. Aircraft could be rerouted by clicking on the aircraft and entering the new letter route on the side panel in the text box. Potential conflicts between aircraft could be avoided by changing the speed and altitude (but not the route) of the conflicting aircraft.

Participants were also given practice in managing interruptions. Interruptions were presented on the side panel of NextSim through a textbox. Participants were alerted to an interruption through a beeping tone which would stop once they clicked on the textbox. The textbox identified the type of interruption (Weather report or Pilot request). The weather interruption presented reports about inclement weather in specific parts of the airspace. The pilot request presented a ProM task – remembering to change the speed on an incoming aircraft. Once participants clicked on the textbox, they could read the information contained in the interruption. Participants then entered “OK” in the text box and clicked on “Submit” to dismiss the interruption.

After participants became acquainted with NextSim, they were given instructions for the experiment. Participants were told that their primary task was maintaining minimum separation distance between aircraft. However, along with maintaining minimum separation distances, they had to remember to perform another task. Specifically, they were told to remember to reroute any U5 type of aircraft to f-d-s. Participants were instructed to wait until the U5 aircraft reached waypoint f and then enter the new route.

Following the instructions on the main task, participants were presented with the Symmetry Span task (Kane et al., 2004). This task was a filler task to ensure that participants did not rehearse the instructions of the ProM task. After participants finished the span measure, the instructions for only the ongoing task of monitoring for aircraft conflicts was repeated and the main part of the experiment was begun.

Each participant completed one 20-minute scenario. Each scenario began with approximately eight aircraft in various parts of the airspace. Participants cycled through the two interruption conditions (weather interruption and ProM interruption) in counterbalanced order. The transition between conditions was seamless to the participants. Within the scenario, there was a pair of aircraft that violated minimum separation distance and flashed red because of impending collision. Participants were expected to intervene to avoid the collision by changing the altitude and/or speed of the aircraft. The conflicts never occurred at the time of presenting an interruption, or when a ProM target aircraft reached waypoint f.

Participants experienced two interruptions while monitoring for aircraft conflicts – an interruption that gave information about the weather, and an interruption that presented one of the three interrupting ProM tasks. The interruptions occurred at a random time in every 10-minute block, corresponding to the two conditions in each scenario. The duration of each interruption was 30 seconds from when the participant clicked the textbox to access the interruption. The timings of the interruptions were randomly determined with the constraint that an interruption did not overlap with the occurrence of a conflict between aircraft.

Table 2 illustrates the order of presentation of the ProM aircraft in the Weather 1st interruption condition. If participants were in the Weather 1st condition they received a weather interruption which alerted them to inclement weather in a part of the airspace. Approximately 2.5 minutes after the occurrence of the weather interruption the interrupted ProM aircraft (U5) appeared on the screen and proceeded to waypoint f. Participants were expected to detect the U5 aircraft within 60 seconds and reroute it to f-d-s. This occurred in the first ten minutes of the scenario.

In the latter 10 minutes participants continued to one of the three ProM interruptions, depending on their condition. Participants were interrupted with instructions on the interrupting ProM tasks. Approximately 2.5 minutes after the occurrence of the ProM interruption, the interrupting ProM aircraft appeared on the screen and proceeded to waypoint f. Participants were expected to detect the aircraft within 60 seconds and to reroute it to the appropriate waypoint as instructed in the interruption. Approximately 2.5 minutes after the appearance of the interrupting ProM aircraft, the interrupted ProM aircraft (U5) appeared on the screen and proceeded to waypoint f. Participants were expected to detect the U5 aircraft within 60 seconds and reroute it to f-d-s.

Thus, every scenario contained two occurrences of the initial ProM task – one associated with the weather interruption and one associated with the ProM interruption. Table 3 illustrates the order of presentation of the ProM aircraft in the Weather 2nd interruption condition.

After the conclusion of the experiment, participants were administered a post-experiment questionnaire. The questionnaire queried them about the details of the interruptions, whether they used any strategies to remember the ProM tasks, and whether they experienced aircraft conflict in the scenario.

CHAPTER 3

RESULTS

Dependent variables (DV)

The dependent variables were only measured for the transfer phase of the experiment. In the transfer phase in paired associate learning, participants are presented with the original stimulus, A, and are expected to respond with the original response of B. In the current experiment, the transfer phase consisted of the presentation of the intent trigger of the interrupted ProM task, a U5 aircraft, which they had to remember to reroute to f-d-s.

Intent trigger

The first DV, intent trigger, consisted of detecting the interrupted ProM aircraft within 60 seconds of its appearance. Participants experienced two opportunities of detecting an interrupted ProM aircraft - one following the weather interruption and one following the ProM interruption. Each instance of detection of the interrupted ProM aircraft within 60 seconds was given a score of 1 on the DV of intent trigger. Participants who failed to detect an interrupted ProM aircraft within 60 seconds were given a score of 0.

Sixty seconds was chosen as the window of opportunity of detecting the interrupted ProM aircraft because within that time period the aircraft had progressed very close to the next waypoint in its original route. Thus, after 60 seconds, the aircraft was too far away from the waypoints to which it was supposed to have been re-routed to, and was thus technically “off-route.”

Content recall

The second DV was the recall of the content of the triggered action (content recall), or specifically remembering to enter the correct route on the interrupted ProM aircraft. The opportunity of recall of the action followed the opportunity of detecting the intent trigger. Each instance of entering the correct route on the interrupted aircraft was given a score of 1 on the DV of recall of the action. Participants who failed to enter the correct route on an interrupted ProM aircraft were given a score of 0.

Data processing

Conditionalizing content recall on detection of intent trigger

The scores on the DV of content recall were conditionalized on scores on the DV of intent trigger. In cases where participants had not detected the trigger, content recall would not be counted as a ProM opportunity. This conditionalization will henceforth be referred to as "Level 1 conditionalization."

Conditionalizing the interrupted ProM aircraft on detection of intent trigger of interrupting ProM aircraft

Scores on the U5 aircraft following the ProM interruption were conditionalized further. In the ProM interruption condition, the interrupting ProM aircraft appeared first, followed by the interrupted ProM aircraft. Technically, participants were able to click on an interrupted ProM aircraft and reroute it without having previously detected the interrupting ProM aircraft. However, it is possible that participants did not attend to the ProM interruption, and thus missed detecting the interrupting ProM aircraft. To account for this possibility, it was decided that participants could receive a score on the intent trigger (and consequently, the content recall) of the interrupted ProM aircraft only if they detected the intent trigger of the earlier occurring interrupting ProM aircraft. This conditionalization acted as a manipulation check because it ensured that the intended interruption was detected and acted upon by the participant before the transfer test. This conditionalization will henceforth be referred to as "Level 2 conditionalization."

Hypotheses 1 and 2 compared transfer performance following the type of interruption (weather vs. ProM). The DV in hypothesis 1 was detection of the intent trigger; the DV in Hypothesis 2 was content recall.

Hypotheses 3 and 4 compared transfer performance following the type of ProM interruption (AB, CD vs. AB, CB and AB, CD vs. AB, AD). The DV in Hypothesis 3 was detection of the intent trigger. The DV in Hypothesis 4 was content recall.

The data were processed with Level 1 and Level 2 conditionalizations. The four hypotheses were then analyzed using logistic regression. Logistic regression was most appropriate because the data were scored in the format of 0 or 1 point.

Hypothesis 1

Participants will detect fewer interrupted aircraft in a timely manner in the AB, CD ProM interruption condition as compared to the AB, CD weather interruption condition.

Table 4 presents the proportion of people who detected the intent trigger in each experimental condition. To test Hypothesis 1 detection of the intent trigger in the AB, CD condition in the transfer phase following the weather interruption was compared to transfer performance following the ProM interruption. Logistic regression analysis revealed a significant effect of the type of interruption on detection of the intent trigger, $z = -1.77$, $p < .05$, 1-tailed-test. A significantly greater proportion of interrupted aircraft following the weather interruption was detected as compared to interrupted aircraft following the ProM interruption. Hypothesis 1 was supported by logistic regression.

The ProM literature would predict that as compared to remembering to perform a single ProM task, presentation of a second, unrelated ProM task would recruit additional preparatory attentional processes (Smith & Bayen, 2004). Lower performance on the transfer phase following the ProM interruption condition would thus be explained by the additional attentional resources required to remember to perform the second ProM task.

Hypothesis 2

Participants will recall routes of fewer interrupted aircraft in the AB, CD ProM interruption condition as compared to the AB, CD weather interruption condition.

Table 5 presents the proportion of people who correctly recalled the content in each experimental condition. To test Hypothesis 2 recall of the content in the AB, CD condition in the transfer phase following the weather interruption was compared to transfer performance following the ProM interruption. Logistic regression analysis revealed a marginally significant effect of the type of interruption on recall of the content, $z = -1.52$, $p = .06$, 1-tailed-test. A greater proportion of interrupted aircraft following the weather interruption were correctly rerouted as compared to interrupted aircraft following the ProM interruption. Hypothesis 2 was marginally supported by logistic regression.

The ProM literature would predict that as compared to remembering to perform a single ProM task, presentation of a second, unrelated ProM task would recruit additional retrospective memory processes (Smith & Bayen, 2004). Lower performance on the transfer phase following the ProM interruption condition would thus be explained by the additional memory resources required to recall the content of the second ProM task.

Hypothesis 3

Having the same content associated with two different intents (AB, CB) will be worse than two unrelated prospective memory tasks (AB, CD) on timely detection of the intent trigger.

To test Hypothesis 3, detection of the intent trigger in the transfer phase following the ProM interruption was compared for participants in the AB, CB condition with participants in the AB, CD condition. Results of the logistic regression to analyze hypothesis 3 were not significant, $z = -.48$, $p = .63$, 1-tailed test. To explore whether significant results would be obtained using a less stringent test, the data were also analyzed using independent samples t-test. These results were also not statistically significant, $t(62) = -.31$, $p = .76$. Thus, hypothesis 3 was not supported.

In the AB, CB condition, participants formed a new backward association from B to C in the interpolated learning phase. In the transfer phase, however, they had to reinstate the original backward association of B to A. The data show that as compared to a ProM task which presents a new forward and backward association (AB, CD), a ProM task which only presents a new backward association (AB, CB) did not have an adverse effect on detection of the intent trigger during transfer. In other words, when the second ProM task presents a new intent trigger, performance on detecting the intent trigger is comparable to performing an entirely new ProM task. Thus, a new backward association does not cause sufficient interference to reduce detection of the intent trigger of the interrupted ProM task.

Hypothesis 4

Having the same intent associated with two different contents (AB, AD) will be worse than two unrelated prospective memory tasks (AB, CD) on correct recall of the content.

To test Hypothesis 4, recall of the content in the transfer phase following the ProM interruption was compared for participants in the AB, AD condition with participants in the AB, CD condition. Logistic regression analysis did not yield statistically significant results, $z = 1.44$, $p = .12$, 1-tailed test. An independent samples t-test, however, showed that participants in the AB, AD condition recalled significantly fewer routes than those in the AB, CD condition, $t(62) = -3.48$, $p < .001$. Forward association from A-D may have interfered with the forward association from A-B, resulting in lower performance in the AB, AD condition, as compared to the AB, CD condition (Martin, 1965). Thus, hypothesis 4 was supported by t-test.

In the AB, AD condition, participants formed a new forward association from A to D in the interpolated learning phase. In the transfer phase, however, they had to reinstate the original forward association of A to B. The data show that as compared to a ProM task which presents a new forward and backward association (AB, CD), a ProM task which only presents a new forward association (AB, AD) resulted in worse recall of the content during transfer. Thus, a new forward association significantly interferes with recall of the content of the original ProM task.

However, performance following the weather interruption in the AB, CD condition was superior to the weather interruption in the AB, AD condition, especially if the weather interruption followed the ProM interruption. Weather interruption was a dummy variable and was expected to have similar performance across the three interrupting ProM conditions. Carry over effects from having previously experienced an opportunity to engage in the interrupted ProM task may explain these results. Another possibility is that random assignment of participants across the between-subjects conditions was not successful, and that inherent differences between the participants may have driven the nature of the final results.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

Theoretical implications

Research on associations in ProM so far has only examined the effect of manipulating the degree of association between the ongoing task and the ProM task (Gollwitzer, 1999; Nowinski & Dismukes, 2005). The current study is the first to investigate the effect of changing the association between the components of a ProM task – the intent trigger and content recall. Specifically, the current study interfered with forward and backward associations between the intent trigger and content recall by presenting a second ProM task to participants. The latter ProM task was similar to the first in either intent trigger, content recall, or neither intent trigger nor content recall.

It is important to investigate the effect of interfering with intent trigger-content recall associations in ProM, especially in safety-critical, dynamic environments such as air traffic control. Dynamic environments may present interleaved ProM tasks to operators. Subsequently-presented ProM tasks which share similarities with previously-encoded ProM tasks may interfere with accurate recall of both tasks. Such failures in the context of safety-critical dynamic environments may mean potentially significant losses of resources.

In addition to investigating the effect of similarity between ProM tasks on their completion, the current research also used a unique methodology in which interruptions were used to present ProM tasks. Previous research has demonstrated the adverse effect of interruptions on ProM performance, presumably because of task switching costs imposed by interruptions (McDaniel et al., 2004). An additional novel contribution of the current research was investigating whether being interrupted with a ProM task would further worsen performance of the original ProM task. This question has a bearing on dynamic, interruption-laden environments in which operators may be frequently interrupted in their current tasks with requests to perform other higher-priority tasks. Worse performance on a relatively cognitively-demanding ProM interruption which interferes with previously-encoded ProM tasks as compared to a routine interruption may have an implication on the development of aids to manage interleaved ProM tasks.

The results did, in fact, find worse performance on the original ProM task in the ProM interruption condition as compared to the weather interruption condition. Participants were significantly worse in detecting the Intent Trigger; however there was marginal significance for the dependent measure of Content Recall. Thus, detecting the Intent Trigger and Recalling the Content were more challenging when faced with a resource-demanding interruption which presented a ProM task.

Another reason why transfer performance following the ProM interruption was worse than that following the weather interruption was because of interference posed by the ProM interruption. Unlike the weather interruption, the ProM interruption interfered with forward and backward associations between the Intent Trigger and Content Recall of the original ProM task (Underwood & Keppel, 1963). Retroactive interference from the ProM interruption thus resulted in lower ProM performance (Underwood & Schulz, 1960).

Not all ProM interruptions were equally disruptive of the performance of the original ProM task. A task which presented a new backward association (Recalling the same Content, but to a different Intent Trigger, AB, CB), was no better or worse than doing two unrelated ProM tasks (AB, CD) on the detection of the Intent Trigger. However, a task which presented a new forward association (Recalling a new Content, but to the same Intent Trigger, AB, AD) was worse than performing two unrelated ProM tasks (AB, CD) on Recall of the Content. Impairment in recalling the original content stems from difficulty in relating the same stimulus to two different responses (Martin, 1965). However, this finding was detected only through t-tests, and not the more stringent logistic regression. Nevertheless, it may be tentatively concluded that ProM tasks which interfere with forward association are harder to recall than tasks which only interfere with backward association, or which present an entirely new task.

Practical implications

The importance of understanding the effect of changing forward and backward association can be appreciated in the context of interrupt-driven, dynamic environments such as air traffic control (ATC). Dynamic environments may present multiple, interleaved ProM tasks to operators. In ATC, forgetting to perform ProM tasks (e.g., issuing different altitudes to two aircraft traveling the same route at the same time) is likely to result in substantial negative consequences. Based on the findings from the current study, designing memory aids which strategically alert operators towards the Intent Trigger are likely to aid ProM performance.

There is some evidence in support for designing aids that capture attention just in time of the occurrence of the Intent Trigger (McDaniel et al. 2004). McDaniel et al. (2004) found that when participants experienced an interruption before the execution of a ProM task, a memory aid cuing the Intent Trigger aided ProM performance relative to no aid. Such an aid would be useful in the case of a single ProM task. However, designing aids to cue multiple ProM tasks is likely to be challenging because every unique ProM task may have to be associated with a unique memory aid.

In the case of interleaved ProM tasks, however, it may be worthwhile to explore the benefit of using memory aids which not only alert the operator towards the Intent Trigger at the appropriate time, but also present the Content of the ProM task (Loft et al., 2011). However, Loft et al. (2011) also found that whereas just-in-time flashing aids helped ProM performance, the aid to ProM was at the cost of slower performance on the ongoing task. Therefore, it is important that the design of memory aids in dynamic environments take into consideration not only the cognitive resources required to perform ProM tasks, but also the resources required to perform ongoing tasks in a timely and accurate manner.

It is possible that different types of ProM tasks require different types of aids, depending on the extent to which they interfere with Intent Trigger-Content Recall associations of previously-formed ProM tasks. The current study demonstrates that although ProM interruptions generally hurt performance on interleaved ProM tasks, recall of the content is most affected by tasks which interfere with forward associations. Future studies could investigate whether performance on tasks which change forward associations is benefitted by a salient, just-in-time reminder about the ProM content. Tasks which interfere with backward associations, on the other hand, could possibly be managed with only a just-in-time alert about the Intent Trigger.

In conclusion, the current study presented a novel view of associations in ProM. Conceptualizing a ProM task in terms of forward and backward associations was useful in understanding the effect of interfering with individual components of ProM.

Future study

The results from the current study should be interpreted with the caveat that the control condition of the non-ProM interruption, weather, did not yield similar mean scores across the three levels of the interrupting ProM task. We have planned a follow-up experiment that changes this condition to a between-subjects factor. Thus, participants in the new experiment will only experience one interruption – weather, intent change, content change, intent + content change.

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Table 1

Instructions for the Three Types of ProM Interruptions and the Weather Interruption

Condition name	Intent-Content of interrupted ProM task	Intent-Content of interrupting ProM task	Representation in terms of paired associates learning	Interrupted ProM task instructions	Interrupting ProM task instructions
Intent trigger + Content recall change	A-B	C-D	AB, CD	Reroute U5 aircraft to f-d-s from waypoint f	Reroute ONLY <u>next</u> E9 aircraft to j-d-p from waypoint f
Intent trigger change	A-B	C-B	AB, CB	Reroute U5 aircraft to f-d-s from waypoint f	Reroute ONLY <u>next</u> E9 aircraft to f-d-s from waypoint f
Content recall change	A-B	A-D	AB, AD	Reroute U5 aircraft to f-d-s from waypoint f	Reroute ONLY <u>next</u> U5 aircraft to j-d-p from waypoint f
Weather interruption	A-B	NA	AB	Reroute U5 aircraft to f-d-s from waypoint f	NA

Table 2

Task Flow of the Experiment in the Weather 1st Interruption Condition

1. Instructions for the interrupted ProM task
2. Weather interruption (“Thunderstorms near waypoint m.”)
3. Appearance of initial ProM aircraft at waypoint f (participant clicks on the aircraft and reroutes it to f-d-s)
4. Presentation of ProM interruption (Instructions for one of the three interrupting ProM tasks)
5. Appearance of interrupting ProM aircraft at waypoint f (participant clicks on the aircraft and reroutes it appropriately)
6. Appearance of interrupted ProM aircraft at waypoint f (participant clicks on the aircraft and reroutes it to f-d-s)

Table 3

Task Flow of the Experiment in the Weather 2nd Condition

1. Instructions for the interrupted ProM task 2. Presentation of ProM interruption (Instructions for one of the three interrupting ProM tasks) 3. Appearance of interrupting ProM aircraft at waypoint f (participant clicks on the aircraft and reroutes it appropriately) 4. Appearance of interrupted ProM aircraft at waypoint f (participant clicks on the aircraft and reroutes it to f-d-s)
5. Weather interruption ("Thunderstorms near waypoint m.") 6. Appearance of interrupted ProM aircraft at waypoint f (participant clicks on the aircraft and reroutes it to f-d-s)

Table 4

Proportion of Correct Detections of the Intent of the Interrupted ProM task for the Interrupting ProM Tasks, the Order of Presenting the Interruptions, and the Type of ProM tasks

		Type of Interruption							
		Weather Interruption				ProM Interruption			
Type of Interrupting ProM Task		CB	AD	CD	Mean	CB	AD	CD	Mean
Order of Presenting Interruption	Weather First	.94 *(.25)*	.81 *(.4)*	.88 *(.34)*	.87 *(.33)*	.87 *(.34)*	.75 *(.45)*	.81 *(.4)*	.81 *(.39)*
	Weather Second	.81 *(.4)*	.75 *(.45)*	1 *(0)*	.85 *(.36)*	.75 *(.45)*	.63 *(.5)*	.75 *(.45)*	.71 *(.46)*
	Mean	.87 *(.34)*	.78 *(.42)*	.94 *(.25)*		.81 *(.4)*	.69 *(.47)*	.78 *(.42)*	

Note. Standard deviations are in parentheses.
There were two levels of the type of interruption: the weather interruption and the ProM interruption.
There were three levels of the Type of ProM interruption: intent trigger change (CB), content recall change, (AD), and intent trigger + content recall change (CD).
There were two levels of the order of presenting the interruption: Weather interruption first followed by the ProM interruption (Weather first) and the ProM interruption followed by the Weather interruption (Weather Second).
The dependent variable was the proportion of participants who detected the appearance of the interrupted aircraft, U5, at waypoint f.

Table 5

Proportion of Correct Performance of the Content of the Interrupted ProM task for the Interrupting ProM Tasks, the Order of Presenting the Interruptions, and the Type of ProM tasks

		Type of Interruption							
		Weather Interruption				ProM Interruption			
Type of Interrupting ProM Task		CB	AD	CD	Mean	CB	AD	CD	Mean
Order of Presenting Interruption	Weather First	.69 *(.48)*	.69 *(.48)*	.81 *(.4)*	.73 *(.45)*	.69 *(.48)*	.50 *(.52)*	.75 *(.45)*	.65 *(.48)*
	Weather Second	.69 *(.48)*	.56 *(.51)*	.94*(.25)*	.73 *(.45)*	.63 *(.5)*	.44 *(.51)*	.69 *(.48)*	.58 *(.5)*
	Mean	.69 *(.48)*	.63 *(.49)*	.87 *(.34)*		.66 *(.48)*	.47 *(.51)*	.72 *(.46)*	

Note. Standard deviations are in parentheses.
There were two levels of the type of interruption: the weather interruption and the ProM interruption.
There were three levels of the Type of ProM interruption: intent change (CB), content change, (AD), and intent + content change (CD).
There were two levels of the order of presenting the interruption: Weather interruption first followed by the ProM interruption (Weather first) and the ProM interruption followed by the Weather interruption (Weather Second).
The dependent variable was the proportion of participants who correctly rerouted the interrupted aircraft, U5, to f-d-s.

Figure 1

Intent trigger – Content Recall Representation of the Prospective Memory Conditions in Terms of Paired Associate Learning Paradigms

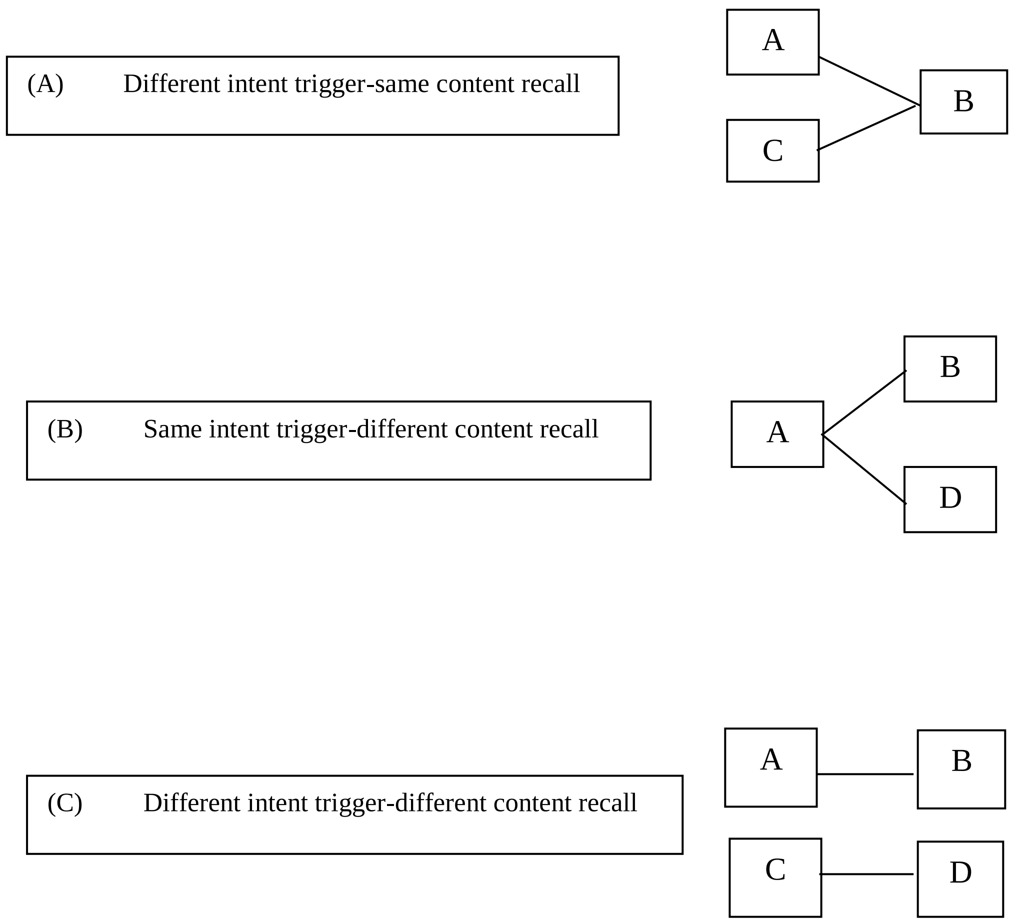

Figure 2

Sequence of Presentation of the Prospective Memory Tasks

Instructions for interrupted ProM task (U5 to f-d-s)

Interruption presents instructions for interrupting ProM task

Interrupting ProM task cue

Interrupted ProM task cue (U5)